5 AEROSPACE AMERICA MAY 2012

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Human space exploration

A GLOBAL QUEST

Snaring a piece of the sky

Hypersonic transport...30 years and holding

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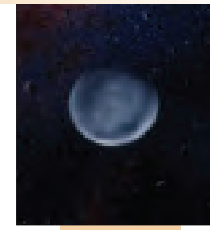


Snaring a piece of the sky

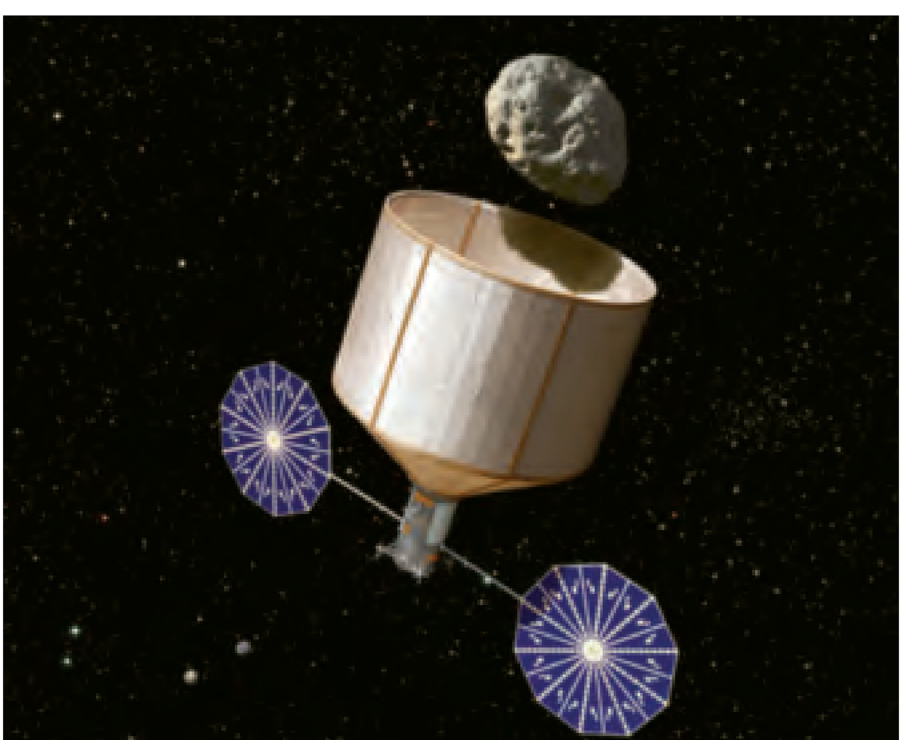
A team of experts organized by the Keck Institute for Space Studies (KISS) wants NASA and its partners to grab a nearby asteroid and return it to cislunar space, opening the door to astronaut operations, scientific exploration, and commercial mining of these ancient, chemically diverse bodies.

The robotic mission to retrieve a near-Earth asteroid (NEA) roughly 7 m across fits neatly into NASA's plans for human missions to larger asteroids, and would establish another science- and resource-rich destination for astronauts in cislunar space. Visits to the captured asteroid from either LEO or an Earth-Moon L2 outpost could build human spaceflight experience and reduce the risks of deep-space voyages to the Sun-Earth Lagrange points and accessible NEAs.

The seemingly quixotic idea of snaring a small asteroid has been proposed before. Science fiction writers have long been drawn to the idea of capturing a near-Earth asteroid and propelling it back to Earth orbit, there to be mined or dropped on the head of some observatory-deficient, downward-looking enemy. Space futurists contemplate capturing large asteroids into cislunar space to provide megatons of recoverable metals and volatiles. Five years ago, Constellation engineers examined the possibilities of having astronauts grapple a basketball-sized asteroid onto their Orion spacecraft and returning it to Earth.

A KISS-commissioned team examined the feasibility of an asteroid capture and retrieval mission, devoting six months of analysis and two workshops at Cal Tech to the concept. This author contributed to the study, led by JPL's John Brophy, Cal Tech's Fred Culick, and the Planetary Society's Lou Friedman. The *Asteroid Retrieval Feasibility* study had three goals:

- Determine the feasibility of robotically capturing and returning a small NEA to Earth's vicinity, using technology available *within this decade*.
- Identify the benefits of such an endeavor to NASA, the science and aerospace communities, and society.
- Identify how such a mission could aid NASA and its partners in their plans for human exploration beyond LEO.



After matching spin rate and orientation with the asteroid target, the ACR spacecraft closes in to swallow it within the capture mechanism. Cinching cables would tighten to retain and restrain the asteroid for despin and SEP transport back to cislunar space. Artist credit: Rick Sternbach/KISS.

Why reach for an asteroid?

NASA is already sending robots to asteroids: Dawn is orbiting Vesta, and OSIRIS-REx launches in 2016 to the C-type NEA 1999 RQ36, aiming to return a 2-oz sample to Earth in 2023. The agency's Human Exploration and Operations Directorate (HEO) plans to conduct astronaut NEA expeditions by 2025. These missions, meant to last six months or more, will characterize, sample, and prospect objects tens to hundreds of meters in diameter.

However, proposed NASA budgets fall short of a 2025 NEO mission capability, and several major preparatory steps for such an expedition have yet to be tackled. Specifically, the agency has yet to obtain funds to launch a space-based search for smaller NEAs, which are more numerous and so statistically more likely to be accessible via the Orion/Space Launch System. Nor can HEO afford precursor asteroid missions, designed to scout the way for astronaut expeditions. These delays stack up: If it takes 10 years to conduct the search and compile a list of possible human targets, the need for subsequent robot scouting missions will force the first human NEA expedition well past 2025.

This timing opens up a window

NASA will launch a spacecraft to an asteroid in 2016 and use a robotic arm to pluck samples that could better explain our solar system's formation and how life began. OSIRIS-REx will be the first U.S. mission to carry samples from an asteroid back to Earth. Credit: University of Arizona.

for a robotic foray to grab a small NEA (or pluck a large boulder from a larger asteroid), then move it into a safe parking orbit around the Moon. There, robots and astronauts can literally dismantle the object in the name of science, operations experience, planetary defense engineering, and commercial prospecting.

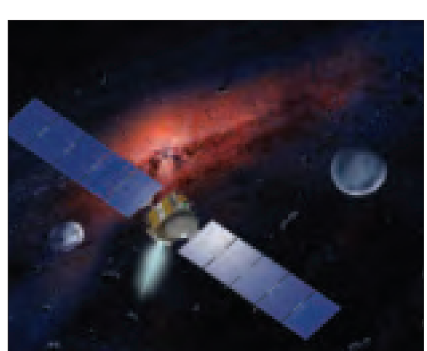
The retrieval of a sizeable, well-chosen body will enable a revolution in scientific analysis of primitive materials dating back to the solar system's origin. Equally important will be the benefits of putting astronauts, operating in the Moon's vicinity by the 2020s, in contact with bulk asteroidal material. Astronauts, perhaps operating from the EM L2 Lagrange point, would get repeated opportunities to test proximity operations, evaluate anchoring gear, repeatedly examine a two-story-tall asteroid, set up water and resource-extraction equipment, and obtain the civil engineering information needed for effective planetary defense. Follow-up missions could focus on commercial exploitation of the hundreds of tons of NEA feedstock.

Mission overview

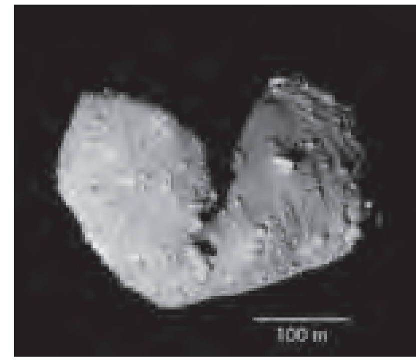
The Asteroid Capture and Return (ACR) mission would be executed by a robotic spacecraft employing solar-electric propulsion (SEP). Launched into LEO by an Atlas-V-class booster, the spacecraft deploys its 10.7-m arrays and, under ion thrust, spirals out to the Moon in about two years. Successive lunar gravity assists help the SEP execute an escape from Earth's gravity; cruise to the asteroid takes another two years.

Once rendezvous with the target is achieved, the spacecraft determines the object's spin state, diameter, and surface topography. Deploying a flexible, wide-mouthed fabric capture bag, the ACR spacecraft moves in, matches rotation, then engulfs and 'hugs' the asteroid. After capture, the spacecraft thrusters stabilize and despin the object, and the SEP system begins a 2-6-year transit to Earth.

The NEA target diameter of around 7 m was chosen to maximize the probability of finding a suitable target using ground-based telescopes, yet minimize the propellant needed to return the asteroid to cislunar space. The captured NEA would have a mass anywhere from 250,000 to 1 million kg, roughly equal to that of the ISS. (Six Apollo missions returned 382 kg of lunar samples to Earth.) Even this massive an object poses little danger to Earth: C-type asteroids possess very low physical strength and would break up upon atmospheric entry. To further ensure safety, the ACR mission will



NASA's Dawn satellite is already orbiting the large asteroid Vesta.



The ACR spacecraft could snare and retrieve surface boulders on larger, easier-to-discover NEAs. These large boulders on Itokawa were imaged by Hayabusa on Oct. 23, 2005, from a distance of 4.7 km. Credit: CJAXA.

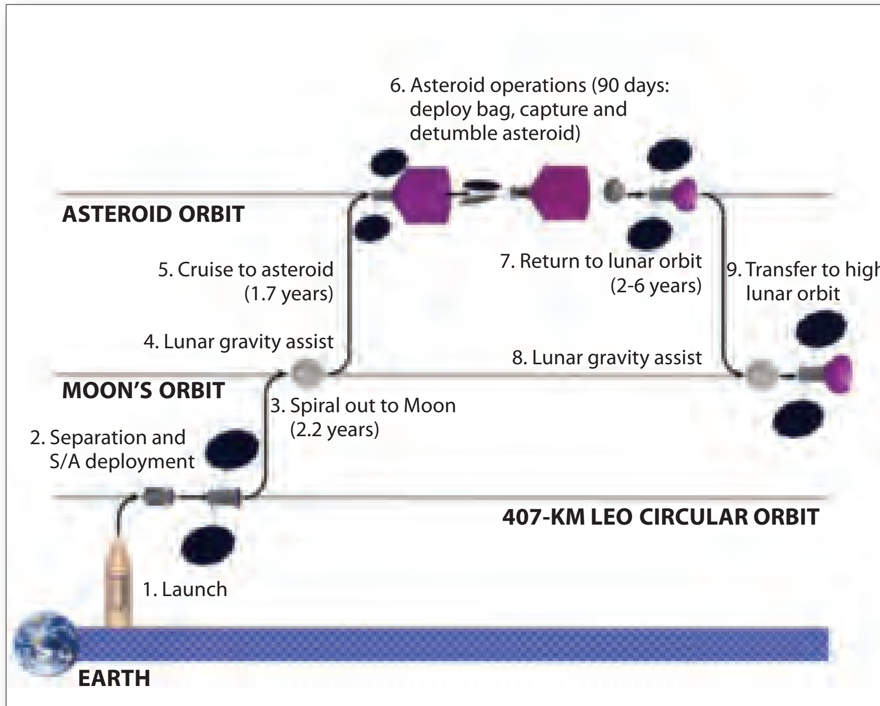
place the NEA in a high lunar orbit. From there, an uncontrolled asteroid would be driven by gravitational perturbations to an impact on the Moon.

Finding a target

Can we expect to find by 2020 a set of 7-m asteroids with orbits accessible to the ACR ion propulsion system? The good news is that there are many millions of NEAs smaller than 10 m across (a 10-m object has a mass of roughly 1.5 million kg). But these small objects are very faint to ground-based telescopes, visible only when close to Earth. Today only a few dozen small, suitably accessible NEAs are known, and we have no information on their spectral type or composition. A concerted search to find a set of accessible NEAs will be necessary if the ACR mission is to be launched within a decade.

The ideal asteroid target will be a C-type object, thought to be similar to carbonaceous chondrite meteorites. Such materials can yield as much as 40% by mass of recoverable volatiles, in roughly equal parts water and complex carbon compounds. The residue after volatile extraction is about 30% native iron and nickel. To identify C-type targets, the search campaign must rapidly cue follow-up observations to detect spectral features indicative of water-bearing surface minerals.

The study estimated that a low-cost ground-based telescopic campaign could sort through the 3,500 new NEA discoveries made each year and identify about five 'good' ACR candidates. These would possess the right size, mass, shape, spin state, required C_3 launch energy, synodic period, and water-rich composition.



How to steal an asteroid

NASA Glenn's COMPASS design team, working with the KISS study staff, developed an ACR spacecraft concept based on existing space systems. The 6-m spacecraft bus is flanked by a pair of 10.7-m solar arrays to power the 40-kW SEP system. Atop the bus is stowed an inflatable, 10x15-m capture bag. The solar array wings span some 36 m, making for a large spacecraft, but it's going after big game.

The SEP system consists of five gimbaled Hall thrusters (four plus a spare) and a set of seven xenon tanks holding 12,000 kg of propellant. The system operates at a specific impulse of 3,000 sec. During NEA proximity and despin operations, ACR uses a bipropellant reaction control system employing four sets of thruster quads.

Opposite the Hall thrusters are the sensor package and capture mechanism. To characterize the NEA and provide guidance during proximity and capture operations, ACR carries four science cameras, four guidance cameras, an illumination system, a pair of LIDARs, and a pair of near-IR science spectrometers. Redundancy in the imaging systems is crucial, giving flight controllers the necessary situational awareness during approach and capture.

Once deployed, the capture mechanism resembles the open end of a funnel. The mechanism combines inflatable deployment arms, two or more inflated circumferential hoops, a high-strength fabric bag, and cinching cables. The inflatable arms and hoops hold the bag open as the spacecraft matches the asteroid spin and eases over the asteroid. The bag can contain an irregular object roughly 6x12 m in dimension, with a surface that is either solid, or weak and crumbly.

Once the asteroid is enveloped, cinching cables draw the bag closed and snug it up against the spacecraft to provide the surface contact necessary for despinning. About 300 kg of propulsion is sufficient to detumble the roughly 500-ton asteroid. The bag fabric has the right surface thermal properties to maintain the asteroid at or below its temperature at grapple.

Should search programs fail to discover enough small, C-type NEAs to enable capture of a free-flying asteroid, the team suggested an alternate, 'pick up a rock' approach. The ACR spacecraft would rendezvous instead with a larger, roughly 100-m asteroid and target a surface boulder for retrieval. The ACR capture mechanism would be flown over a suitable boulder and the bag cinched closed. RCS thrusters would then pull the boulder free of the regolith and the asteroid's milli-*g* gravity. If a boulder won't come loose, a snow-blower-style scoop at the mouth of the capture bag could gather tons of regolith into the fabric enclosure for return to Earth.

On return to cislunar space, the ACR craft and asteroid in-tow perform a lunar gravity assist and are captured by Earth. Additional SEP thrusting puts the asteroid into a high lunar orbit, where roughly 10 m/sec of delta-V annually will suffice to maintain it there for at least 20 years. Total cost for the mission is estimated at roughly $2.6 billion over a decade (in 2012 dollars).

Exploiting 'The Rock'

The captured asteroid, tended by its ACR spacecraft, would then be open to intensive exploration, exploitation, and dissection by both robotic and astronaut visits. NASA and its partners could sequence a series of robotic scientific missions to the object, much as cargo traffic is controlled at the ISS, conducting in-situ analysis, Earth sample return, resource extraction demonstrations, and assessment of physical and chemical properties.

As astronauts set up shop at the EM L2 'line shack' and habitat now being evaluated by NASA for the early 2020s, the captured asteroid would be a natural destination. Orion sorties to the NEA would be, in effect, human asteroid missions, reducing the risk for the full-fledged NEA missions to follow. An Orion crew could conduct multiple approaches, rehearse proximity operations, anchor, and 'dock' to the asteroid.

Astronauts would gradually peel back the capture bag, drawing back the curtain, so to speak, on an ancient, resource-rich asteroid. Close-up examination would reveal its morphology, composition, and 'topography,' and assess the physical state of its soil and bedrock. Gamma ray and neutron spectrometers would measure bulk composition before dissection begins.

Crew surface activities would progress from surface sampling to core sampling to testing anchoring strategies to extraction of water and other volatiles and finally to demonstrations of various bulk material handling and mining techniques. These activities would greatly advance asteroid science, human operations, resource extraction, and planetary defense engineering. Each Orion crew could return about 100 kg of material to Earth for analysis. After in-depth study, NASA and its partners could negotiate the handover of hundreds of tons of asteroidal material to commercial mining and resource delivery interests.

An 8-m boulder that crashed down a hillside into an Ohio house in March is about the size of the small asteroid the ACR mission would return to high lunar orbit. Credit: G.S. Springer.

International exploration context

The ACR study showed that the technologies needed for the mission—SEP, high-power solar arrays, trajectory design, autonomous proximity and capture operations, and capture bag mechanisms—are all in hand or could be flight qualified by 2020. The proposed space-based IR survey mission NASA needs to identify hazardous NEAs and promising human exploration targets would also help discover the candidates for ACR.

Thus, the capture and return of a 500-ton asteroid to cislunar space could be accomplished by the middle of the next decade. This delivery date fits well into the progression of human spaceflight capabilities NASA envisions through 2030. If human NEA missions are delayed by budgetary or technical problems, the robotic ACR mission bridges the waning years of ISS operations and paves the way for true NEA expeditions.

The ACR mission seems to offer an affordable, logical step supporting human deep space expeditions in five specific ways:

• As a robotic precursor mission, ACR rehearses many of the phases of an astronaut NEA expedition and feeds that experience forward.

• ACR enables 'local' astronaut trips to an NEA lasting only a few weeks, building a bridge between LEO operations and true deep-space expeditions.

• Putting tons of bulk asteroidal material within reach of a human-tended EM L2 facility enhances the scientific, economic, and operational value of such an exploration gateway.

• The availability of hundreds of tons of asteroidal feedstock opens the door to large-scale use of extraterrestrial resources by NASA and its commercial partners, with the potential to jump-start an entire space-based industry to produce propellants and radiation shielding.

• The challenging, lengthy process of dissecting a 500-ton asteroid will engage the public and provide a steady stream of 'real-time' exploration experiences inviting community problem-solving. Imagine a televised, team competition aimed at coming up with the best and cheapest methods of extracting ores and tapping this new wealth from space.

The ACR mission also invites international cooperation in target search, hardware design and delivery, scientific study, commercial exploitation, and planetary defense engineering (by definition, ACR is an 'asteroid deflection mission').

Taken together, these benefits might entice NASA and its partners to develop ACR. The result would be a demonstrated deep-space capability that has not been seen since Apollo. The returned asteroid would put the Orion astronauts in touch with an ancient, scientifically intriguing, and commercially valuable body beyond the Moon, an achievement that would compare very favorably to missions that appear to merely repeat those Apollo landings of a half-century ago. NASA should take a good look at the ACR concept as it looks to construct an affordable path into deep space.

The *Asteroid Retrieval Feasibility* report is available via http://kiss.caltech.edu/people/contact.html.

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